ACTIVE EDGE GRIPPING END EFFECTOR

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Field of the Invention:

[0001] The present invention generally relates to an end effector for acquiring and transporting semiconductor wafers. More particularly, the present invention comprises an end effector that includes a mechanical actuator having the ability to vary the gripping force exerted by a gripping mechanism on a wafer.

Background of the Invention:

[0002] Various types of wafer-handling robots are known for transporting the wafers to and from the FOUP and among processing stations. Many such robots employ a robotic arm having a spatula-shaped end that is inserted into the cassette to remove or insert a wafer. The spatula-shaped end of the robotic arm is commonly referred to as an end effector. One type of end effector secures the wafer contact surface to the wafer by a vacuum source. The vacuum source pulls the bottom surface of the wafer into contact with the entire wafer contact surface.

[0003] With many workpieces, and certainly with semiconductor wafers, the surfaces of the workpieces can be easily damaged if the wafer-handling robot contacts the top or bottom surface of the wafer. Because of this, the wafer-handling robot should preferably contact only the peripheral edge of the wafer, or at most, the bottom surface within a narrow distance from the edge (known within the semiconductor industry as the "edge exclusion zone"). A wafer-handling robot must load wafers into and unload wafers from a wafer processing apparatus with a high degree of precision to avoid contacting the critical surfaces of the wafer.

[0004] Fig. 1 illustrates a conventional wafer-handling end effector. The wafer-handling robot **10** supports a wafer **12** by a wafer blade **11** that has a proximal end **12** and a distal end **14**. The distal end **14**, in this configuration, has two spaced apart and substantially parallel fingers – a first finger **16** and a second finger **18**. The first finger **16** includes a distal wafer support **20** that contacts the wafer **12** either along the peripheral edge or the Exclusion Zone. The second finger **18** also includes a distal wafer support **22** that contacts the wafer in a similar manner.

[0005] The wafer blade **11** also includes proximal wafer supports **24** and **26**. The proximal wafer supports **24** and **26** also contact the wafer **12** either along the peripheral edge of the wafer **12** or along the Exclusion Zone. The distal wafer supports **20** and **22** include a backstop portion to prevent the wafer **12** from sliding off the wafer blade **11** during transport. A wafer **12** is not always perfectly positioned on the wafer blade **11** such that the peripheral edge of the wafer rests against the wafer supports **20** and **22** at all times. Sudden movement or high rotational speeds by the wafer handling robot **10** may throw the wafer **12** against the supports **20** and **22** and cause damage to the wafer **12,** or cause the wafer **12** to slip over the wafer supports **20** and **22** and off the blade **11**. An example of an end effector similar to that shown in Fig. 1 is disclosed in U.S. Patent No. 6,077,026, issued to Schultz, entitled "Programmable Substrate Support For a Substrate Positioning System," which is assigned to Asyst Technologies, Inc., and is incorporated herein by reference.

[0006] As the robot speed and acceleration increase, the amount of time spent handling each wafer and delivering each wafer to its next destination is decreased. The desire for speed, however, must be balanced against the possibility of damaging the wafer or the film formed on the wafer. If a robot moves a wafer too abruptly, or rotates the wafer blade too fast, the wafer may slide off the blade, potentially damaging the wafer. Further, particle contaminants may result if the wafer slides around on the end effector. In addition, movement of the wafer on the wafer blade may cause substantial misalignment of the wafer. A wafer that is not aligned may result in inaccurate processing or even additional particle generation.

[0007] Wafer handling robots that grip the wafer by its peripheral edge exist today. By way of example only, one type of robot end effector includes an active contact point that moves between a retracted wafer-loading position and an extended wafer-engaging position that urges the wafer against a pair of distal wafer supports. Another example of a robot end effector includes a pair of arms that grip the peripheral edge of the wafer after the wafer is placed on the blade. The active contact point and the pair of arms retract and extend through a vacuum or pneumatically actuated mechanism. Vacuum and pneumatic actuation mechanisms provide poor control of the maximum force exerted on the wafer, because velocity of the active contact point or the arms cannot be controlled.

[0008] After the end effector lifts a wafer off a cassette support, the active contact point (or the pair of arms) extends to contact the peripheral edge of the wafer and push the wafer against the distal wafer supports. The active contact point holds the wafer in place on the wafer blade. A vacuum actuated gripping device, for example, cannot stop or vary its speed between the retracted wafer-loading position and the extended wafer-engaging position.

[0009] An end effector that incrementally controls the motion of the gripping device, which prevents damage to the wafer, is a desirable feature. An end effector having a real-time force feedback system that monitors the force exerted on the wafer is also a highly desirable feature.

Summary of the Invention:

[0010] One aspect of the present invention is to provide an end effector that creates four points of contact along the peripheral edge of the wafer to improve the centering ability of the end effector. In one embodiment, the gripping mechanism includes two gripping arms and, in combination with two static rest pads, secures the wafer to the end effector. The gripping arms and static rest pads provide four contact points along the peripheral edge of the wafer. In another embodiment, the gripping mechanism includes a plunger having a pair of spaced apart contact pads. The plunger, similar to the gripping arms, provides two contact points along the peripheral edge of the wafer.

[0011] Another aspect of the present invention is to provide an end effector that reduces or eliminates particles created by securing the wafer to the end effector. In one embodiment, the end effector includes a centering device adapted to center the wafer on the end effector before the end effector picks up the wafer. After the wafer is seated on the end effector, a gripping mechanism secures the wafer on the end effector. If the wafer is pre-centered, the wafer will not slide substantially on the end effector, if at all, when the wafer is secured to the end effector by the gripping mechanism. In another embodiment, the contact pads of the gripping mechanism initially contact the peripheral edge of the wafer in such a manner as to minimize any sliding of the wafer.

[0012] Yet another aspect of the present invention is to provide an end effector that provides precise motion control of the contact pads. The gripping mechanism includes a motor assembly that drives a carriage, which is operatively coupled to the gripping arms. In one embodiment, a cam engages the carriage such that the cam's rotational motion drives the translational member along a linear path. The linear motion of the carriage in turn imparts rotational motion to the gripper arms.

[0013] Still yet another aspect of the present invention is to provide an end effector that includes a real-time force feedback system. The force feedback system minimizes the initial impact force exerted by the gripping mechanism against the wafer. The force feedback system also maintains the force exerted by the gripping mechanism against the wafer at a constant state. In one embodiment, each contact pad includes a force sensing device to detect the amount of force the contact pad is exerting on the wafer. The force

sensing device is electrically coupled to the motor assembly to create a closed loop feedback system. In another embodiment, the force feedback system is an open loop system.

[0014] Another aspect of the present invention is to provide an end effector that has optical means for sensing the presence of a wafer. In one embodiment, thru-beam sensors detect a wafer proximate to the digital end of the end effector.

[0015] Yet another aspect of the present invention is to provide an end effector that may approach the wafer from above and pick up the wafer. The gripping surfaces of the wafer are vertical (*e.g.*, the peripheral edge of wafer). The force feedback system ensures that the force exerted by the gripping mechanism on the wafer is sufficient to prevent the wafer from falling off the end effector.

[0016] Still another aspect of the present invention is to provide an end effector that minimizes the initial impact the gripping mechanism places on the wafer. Controlling the speed of the gripping mechanism as it approaches the wafer reduces the large impact force exerted against the wafer that a conventional edge grip device produces (e.g., vacuum actuated plunger). The speed of the gripping mechanism may be controlled – whether the gripping mechanism is a pair of gripper arms or a plunger.

[0017] Yet another aspect of the present invention is to provide an end effector that recognizes when the gripping mechanism attempts to grip a wafer that is not present on the wafer blade. In one embodiment, an "over-travel" position is identified when the gripping mechanism moves to a location that should contact a wafer and yet no contact is made.

<u>Brief Description of the Drawings</u>:

[0018] FIGURE 1 is a top perspective view of a conventional end effector, according to the prior art;

[0019] FIGURE 2 is an assembly view of an embodiment of an active grip end effector, according to the present invention;

[0020] FIGURE 3 is a top view of an embodiment of the end effector shown in Fig. 2, illustrating the gripper arms in a wafer-loading position;

[0021] FIGURE 4 is a top view of an embodiment of the end effector shown in Fig. 2, illustrating the gripper arms in a wafer-engaging position;

[0022] FIGURES 5A-5C illustrate one embodiment of a motor assembly, according to the present invention;

[0023] FIGURES 6 is an assembly view of the motor assembly shown in Fig. 5 in conjunction with a motor mounting block;

[0024] FIGURES 7A-7B illustrate one embodiment of a carriage, according to the present invention;

[0025] FIGURES 8A-8B illustrate an embodiment of a gripper arm, according to the present invention;

[0026] FIGURE 9 is an assembly view of the gripper arm shown in Figs. 8A-8B, illustrating a bearing assembly;

[0027] FIGURE 10 is a top view of the end effector shown in Fig. 2, illustrating the contact point of the gripper arms against the wafer;

[0028] FIGURE 11 is a perspective view of another embodiment of an end effector, according to the present invention;

[0029] FIGURE 12 is a perspective view of yet another embodiment of an end effector, according to the present invention; and

[0030] FIGURE 13 is a perspective view of the edge gripper plunger motor assembly shown in Fig. 12.

Detailed Description of the Invention:

[0031] An end effector **100** manufactured according to one or more embodiments of the present invention will now be described with reference to Figs. 2–13. In general, the end effector **100** includes a gripping mechanism that contacts the peripheral edge of a wafer in order to secure the wafer to the end effector **100**.

[0032] Figs. 2–4 illustrate one embodiment the end effector **100**. In this embodiment, the end effector **100** has a proximal end **112** and a distal end **114**. The distal end **114** of the end effector **102** comprises a wafer blade **111** having two spaced apart fingers **116** and **118**. The distal end of the two fingers **116** and **118** each include a wafer support pad **120** for supporting a portion of a wafer **12** seated on the wafer blade. It is within the scope and spirit of the invention for the wafer blade **111** to comprise a single finger in order to provide a narrower end effector. The wafer blade **111** also includes a proximal wafer support **122** so that a wafer seated on the wafer blade **111** is supported in three areas. As shown in Fig. 3–4, the wafer supports **120** and **122** are spaced apart such that the wafer's geometrical center C is located between the supports.

[0033] The distal wafer supports **120** include a platform **124** and a backstop **126**. The platform **124** may have several configurations. If the platform **124** is, for example, a substantially flat or horizontal surface, the wafer platform **124** will contact the wafer **12** along the exclusion zone when the wafer **12** is seated on the wafer blade **111**. If the platform **124** is a slanted or sloped surface (*e.g.*, a raked surface), the platform **124** will only contact the peripheral edge of the wafer while it is seated on the wafer blade **111**. The backstop **126** extends upward from the platform **124**. The backstop **126** contacts the peripheral edge of the wafer **12** and prevents the wafer **12** from sliding off the wafer blade **111**. It is within the scope and spirit of the invention for the backstop **126** to comprise other shapes such as, but not limited to, an arcuate shape that conforms to the peripheral edge of the wafer **12** and/or a sloped surface.

[0034] The end effector **100** picks up a wafer **12** by sliding the wafer blade **111** beneath the wafer **12** until the backstop **126** is located just past the edge of the wafer **112**. The wafer blade **111** is then raised until the platform **124** contacts the wafer **12**. The end effector **100** raises the wafer **12** off a wafer support and the gripper mechanism

(described later) secures the wafer **12** to the end effector **100**. Releasing the wafer **12** is accomplished by reversing the steps performed to pick up the wafer **12**. The gripping mechanism releases the wafer **12**, lowers the wafer **12** onto a support surface and withdraws from the proximity of the wafer **12**.

[0035] It may be useful on occasion to approach the wafer **12** from its top surface to pick up the wafer **12**. In this embodiment, the wafer **12** is supported substantially by the gripping mechanism. An end effector that approaches a wafer from the top to grip it preferably includes a center finding mechanism (described later) that locates the center of the wafer prior to gripping the wafer. The wafer will otherwise slide on the wafer supports when the gripping mechanism contacts the peripheral edge of the wafer – potentially damaging the wafer. An example of a system for positioning an end effector of a wafer handling robot with respect to a wafer is described in U.S. Patent No. 6,298,280, entitled "Method for In-Cassette Wafer Center Determination," issued to Bonora, *et al.*, which is assigned to the owner of this invention and is incorporated in its entirety herein.

[0036] The proximal end **112** of the wafer blade **111** also includes a mounting area **130**. The mounting area **130** is adapted to receive a printed circuit board ("PCB") **132**, that in one embodiment, includes the controllers for the gripping mechanism. An insulating plate **134** is preferably located between the PCB **132** and the wafer blade **111** to electrically isolate the components on the PCB **132** from the blade **111**.

[0037] Some of the key components of the gripping mechanism, which will be described in more detail later, include a motor assembly **144**, a carriage **160**, a flexible link **190**, and a pair of gripper arms **200**. In the embodiment shown in Figs. 3-4, the gripping mechanism comprises a pair of gripping arms **200**. Fig. 3 shows the gripping arms **200** located in a wafer-loading position. In this position, the contact pads **216** of each gripper arm **200** are retracted away from the peripheral edge **13** of the wafer **12** and the end effector **100** may pick up or drop off a wafer **12**. Fig. 4 shows the gripper arms **200** located in a wafer-engaging position. In this position, the contact pads **216** of each gripper arm **200** contacts the peripheral edge **13** of the wafer **12** and exerts a force on the

wafer **12**. The gripper arms **200** may be moved to any position between the wafer-loading and the wafer-engaging positions.

[0038] Fig. 5A–5C illustrate one embodiment of the motor assembly **144**. The motor assembly **144**, in this embodiment, includes a motor **146**, a planetary gearhead **148,** and a cam **150**. The motor **146** is, for example, a 6mm diameter 1.2-watt brushless D.C. motor that operates between 3,000–4,000 rpm. The motor assembly **144** therefore has a very low profile. A small motor diameter is preferred to provide a low profile end effector. It is within the scope and spirit of the invention for the motor **146** to have a different power rating and/or diameter. Other mechanical devices, such as a leadscrew, may be coupled to the motor **146** instead of the planetary gearhead **148**.

[0039] A planetary gearhead **148** is mechanically coupled to the motor **146** to greatly reduce the speed of the output shaft **152** and provide a greater control over the motion of the cam **150**. The planetary gearhead is preferably coaxially aligned with the motor **146**. A planetary gearhead is well-known in the mechanical areas and does not require further disclosure. In one embodiment, the planetary gearhead **148** provides a 57:1 gear reduction between the speed of the motor shaft and the spread of the output shaft **152**. The planetary gearhead **148**, however, may provide other gear reduction ratios. The output shaft **152** of the planetary gearhead **148**, in this example, rotates fifty-seven times slower than the speed of the motor **146**. The high ratio planetary gearhead **148** allows the motor **146** to precisely control the rotation of the output shaft **152**. For example, the motor must rotate fifty-seven times to impart one revolution of the output shaft **152**. The motor **146** can therefore move each gripper arm **200** a distance equivalent to 1/57 of a rotation of the output shaft **152**.

[0040] Other embodiments of the motor assembly **144** may not include a planetary gearhead. A motor assembly **144** may use, for example, a motor and a leadscrew to drive the cam **150**. Each embodiment of the motor assembly **144** preferably tracks the motion of the motor by hall-effect sensors. Hall-effect sensors are well-known within the art and do not require further disclosure. The location of each gripper arm **200** may be determined by the hall state of the motor **146**. In one embodiment, each Hall state corresponds to 6 microns of movement of the gripping arms **200**.

[0041] The cam **150** is coupled to the output shaft **152**. Fig. 5B illustrates that the geometrical center **E** of the cam **150** is offset a distance **d** from the rotational center **G** of the output shaft **152**. The offset **d** allows the outer edge **151** of the cam **150** to extend beyond the outside perimeter **151** of the planetary gearhead **148**. The rotation of cam **150** imparts linear motion to the carriage **162**. In this embodiment, the carriage **160** may move a total distance equivalent to twice the offset **d**. The carriage **160**, in general, requires a certain range of travel to allow the gripper arms **200** to pick up off center wafers The gripper arms **200**, however, need to do that with a certain amount of force to secure the wafer **12** on the wafer blade **111**.

[0042] Fig. 5C illustrates that the cam **150** may rotate through a 180° range of motion. The furthest position to the left (as viewed in Fig. 5C) is referred to as the rear position and is shown as position R. The furthest position to the right (as viewed in Fig. 5C) is referred to as the forward position and is shown as position F. The total linear travel distance of the cam **150** between the rear position R and the forward position F is shown as distance **D**. The cam **150** may be rotated to any position located between the rear position R and the forward position F.

[0043] Fig. 6 illustrates one embodiment of a mounting block **154** that secures or fastens the motor assembly **144** to the wafer blade **111**. In this embodiment, the mounting block **154** has a channel **156** and a bore **158** to accommodate the motor assembly **144**. The channel **156** is adapted to receive the motor **146** and the planetary gear **148**. The motor **146** and the planetary gearhead **148** are preferably secured to the channel **156** to prevent to motor **146** and the planetary gearhead **148** from rotating within the channel **156**. The bore **158** is located at one end of the channel **156** so that the output shaft **152** extends through the bore **158**. The mounting block **154** includes two alignment holes **159** that dowel pins, as an example, pass through to align the mounting block **154** on the wafer blade **111** (See Fig. 2). It is within the scope and spirit of the invention to mount the motor assembly **144** to the wafer blade **111** in another manner.

[0044] The cam **150** is operatively coupled with a carriage **160** (see Figs. 7A–7B). The rotational motion of the cam **150** drives the carriage **160** along a substantially linear path. In one embodiment, the cam **150** is seated within a drive slot **164** of the

carriage **160**. As the cam **150** rotates, the outer edge **151** of the cam **150** drives the carriage **160** either towards or away from the wafer blade **111**. The width W of the drive slot **164** and the diameter D2 of the cam **150** are preferably substantially equal so that the outer edge of the cam **150** is in contact with the drive slot **164** at all times.

[0045] When the cam **150** rotates, for example, counterclockwise (as viewed in Fig. 5C), it contacts a forward face **163** of the slot **164** and pushes the body **162** of the carriage **160** forward (toward the wafer). The cam **150** continues to drive the body **162** forward until the cam **150** rotates into position F (see Fig. 5C). Similarly, the cam **150** drives the body **162** rearward by rotating the cam **150** clockwise (as viewed in Fig. 5C) towards the rear position R. Since the cam **150** and carriage **160** are in slidable contact with each other, they are preferably manufactured from a low resistance, low wear material to prevent particle generation proximate to the wafer **12**.

[0046] Figs. 7A–7B illustrate one embodiment of the carriage **160** which provides a link between the motor assembly **144** and the gripper arms **200**. One side of the carriage body **162** includes a first guide **170** and a second guide **172** that extend outward from the body **162**. The guides **170** and **172** are preferably spaced apart and substantially parallel to each other. Each guide includes a bore **174**. The bore hole **174** may extend through any portion of the support guides **170** and **172** as long as the geometric center of each bore hole **174** is concentrically aligned with the other.

[0047] As previously discussed above, the carriage **160** travels along a linear path. The bore holes **174** are adapted to receive a guide rail **182**. The carriage **160** slides along the guide rail **182**, which also prevents lateral motion of the carriage **160**.

[0048] It is within the scope and spirit of the invention to restrict the motion of the carriage **160** by devices other than a guide rail **182**. Regardless, the carriage **160** slides along the proximal end of the end effector. In one embodiment, the end effector **100** includes a slot **143** that the carriage **160** slides within. The slot **143** allows the carriage **160** to travel freely back and forth, yet constrains the lateral motion of carriage **160**. In another embodiment, the carriage **160** includes multiple support surfaces (not shown) that extend from the bottom of the carriage **160**. Only the support members contact the wafer

blade **111**, thus provide a smaller contact surface area between the wafer blade **111** and the carriage **160**.

[0049] The carriage **160** is coupled with the cam **150**. One side of the carriage **160** includes a drive slot **164** that the cam **150** sits within. The drive slot **164** extends, in this embodiment, vetically through the body **162** to form a front surface **163** and a rear surface **165**. The drive slot **164**, as shown in Fig. 7A, has a width **w** that is substantially equal to the diameter **d2** of the cam **150** (see Fig. 5C).

[0050] The front portion **166** of the carriage **160** is operatively connected to the flexible link **190**. The front portion **166,** in order to accommodate the flexible link **190**, has a bore **168** extending horizontally through it. In one embodiment, four vertical dowel holes **169** extend from the top surface of the body **162** to the horizontal bore **168**. Dowel pins (not shown), or other fastening devices, may be inserted into the holes **169** to prevent the flexible link **190** from moving laterally (towards or away from the wafer) within the carriage **160**.

[0051] The motor assembly **144**, through the cam **150**, drives the carriage **150**. Any motion by the cam **150** preferably imparts motion to the carriage **160**. The end of cam travel (*e.g.*, cam **150** is located at 0° or 180° degrees), however, may allow a couple degrees of cam motion to translate into no linear motion of the carriage **160**. The cam **150**, in other words, is not doing useful work during some portion. If the cam **150** is allowed to rotate completely to the 0° or 180° position (defined as an "overtravel" position), the cam **150** further may jam or the end effector **100** will lose track of the precise location of the carriage **160**.

[0052] A hard stop device **141** (See Fig. 2) prevents the cam **150** from reaching the overtravel position. The hard stop **141** is positioned such that the guides **170** will contact the hard stop **141** before the cam reaches the forward position **F** or the rear position **R**. In another embodiment, the carriage **160** includes a bore in the top surface that a dowel pin, or other similar device, fits into. The top portion of the dowel pin travels within a track located above the carriage **160** as the carriage **160** moves between its first and second positions. The track prevents the dowel pin from traveling beyond a certain distance in

both the forward and backward directions and will thus stop the travel of the carriage **160** too. When either the guide **170**, or the dowel pin, contacts the hard stop **141** when traveling in the backward direction (away from the wafer), the gripper arms **200** are located at a "home" position.

[0053] Fig. 8A–8B illustrate one embodiment of a gripping mechanism – a pair of gripping arms 200 (see also Figs. 2–4). Each gripper arm **200** preferably comprises a unitary construction and includes a driver portion **208** and a cantilever portion **210**. The driver portion **208** is connected to the flexible link **190**. As shown in Fig. 8A, the driver portion **208** is fastened to the flexible link **190** by a pair of screws or dowel pins **195**. It is within the scope and spirit of the invention to secure the flexible link **190** to the driver portion **208** by other methods such as, but not limited to, a bolt, a screw, welding and the like. The cantilever portion **210** includes a contact pad **216**, a sensor **214**, and a force sensing device **228**. The sensor **214** preferably includes a pair of transmitters **224** and a pair of receivers **226**. Two optical paths are preferred, because a single optical path may be located over the wafer's indicial notch when the wafer **12** is placed on the wafer blade **111**, and thus not recognize that a wafer is located on the end effector **100.**

[0054] A contact pad **216** is secured to the sensor **214** and is the only portion of the gripper arm **200** that contacts the wafer **12**. In this embodiment, the contact pad **216** includes a mounting segment **217** that fastens to the cantilever portion **210** of a gripper arm **200**. It is within the scope and spirit of the invention to integrate the sensor **214** and/or the contact pad **216** into the distal end **218** of the gripper arm **200**. In one embodiment, the contact pads **216** comprise an upper pad **220** and a lower pad **222** to form a "C"-shape contact pad where the wafer **12** sits between the upper and lower pads.

[0055] The force sensing device **228** is located behind the contact pad **216**. A small gap exists between the arm and the back surface of the contact pad. In operation, the gripper arms **200** grip the peripheral edge **13** of the wafer **12** until the gripper arms **200** are pushes back into the load cell. A load cell converts displacement of the contact pad **216** into a measurable voltage difference. An electrical signal that represents the voltage difference is sent to and processed by a microprocessor that controls the operation of the motor assembly **144**. Alternatively, the load sensing device **228** may comprise a strain

gauge. A strain gauge is well known within the art and does not require further disclosure. It is within the scope and spirit of the invention to integrate the load sensing device **228** or strain gauge into a gripper arm **200** or contact pad **216**.

[0056] Movement by the carriage **160** displaces the flexible link **190**. Fig. 9 illustrates that, in one embodiment, each gripper arm **200** contains a ball bearing assembly **230** that is secured to, and rotates about, a post **232**. A ball bearing assembly **230** is well-known within the art and does not require further disclosure. Each gripper arm **200** may also rotate by other means.

[0057] The flexible link **190**, in general, functions as a leaf spring. When the carriage **160** travels away from the wafer **12**, for example, the carriage **160** pulls the center **191** of the flexible link **190** away from the wafer **12** and rotates the gripper arms **200** into the wafer-engaging position (Fig. 4). The flexible link **190** compensates for any amount of wafer offset so that, for example, both gripper arms **200** and **202** engage the wafer **12** even if the wafer is not centered on the wafer blade **111**. The flexible link **190** also prevents overloading of the drive mechanism **144** if an operator manually inserts a wafer of the wafer blade **111**.

[0058] The gripper arms **200** may contact the peripheral edge of the wafer **12** at substantially the same, or at a different, time. Fig. 2–4 illustrate that the carriage **160** is located substantially equally between the gripper arms **200**. The carriage **160** may also be located in other positions relative to the gripper arms **200**. By way of example only, the carriage **160** may be located closer to one gripper arm than the other.

[0059] The default or home position of the gripper arms **200** is the wafer-loading position (see Fig. 3). In the wafer-loading position, the gripper arm **200** are retracted, providing space so that end effector **102** may pick-up a wafer **12**.

[0060] If the wafer **12** is not centered on the wafer blade **111** before the wafer is placed on the end effector **100**, the wafer **12** will slide on the supports as the gripper arms **200** push the wafer **12** against the back stop **126**. The first and second gripper arms **200** rotate towards the wafer **12** and initially contact the peripheral edge **13** of the wafer **12**. The gripper arms **200** minimize the distance the wafer **12** slides on the supports **122** and

124. Fig. 10 illustrates that the contact pads **216** preferably contact the peripheral edge **13** of the wafer **12** such that the center of each pad **216** substantially faces the center **C** of the wafer **12** (indicated by lines A and B in Fig. 10). This contact pattern, in effect, pushes the wafer **12** forward toward each support **120** along a substantially linear line, indicated as arrow **250**.

[0061] The gripper arms **200** exert a force against the peripheral edge **13** of the wafer **12** when the gripper arms **200** are in contact with the wafer **12**. In a preferred embodiment, a force feedback system monitors, in real time, the force the gripper arms **200** exert on the peripheral edge **13** of the wafer **12**. It is within the scope and spirit of the present invention for the force feedback system to periodically monitor the force the gripper arms **200** exert on the peripheral edge **13** of the wafer **12**. Monitoring the force exerted on the wafer may also be controlled through an open loop control method. A predetermined grip motion sequence, for example, may be programmed into the processor. In this embodiment, the end effector **100** would not require a force feedback system to measure the force exerted on the wafer **12**. Instead, the force exerted on the wafer **12** may be approximated through an algorithm.

[0062] The load sensing device **228** is one element of the force feedback system. As previously discussed, the load sensing device **228** measures the force the gripper arms exert on the peripheral edge **13** of the wafer **12**. A load sensing device **228** is located behind each contact pad **216**. The contact pad **216**, when in contact with a wafer **12**, is pushed back slightly into the force sensing device **228**. The contact between the contact pad **216** and the force sensing device **228** generates an electrical signal that is sent to a processor through the flex circuit **240**.

[0063] The processor processes the signal and sends an appropriate control signal to the motor assembly **144**. For example, if a wafer is not gripped, the force sensing device **228** will read a calibrated "zero" force, and the sensor **214** will not see the wafer edge **13**. The motion of each gripper arm **200** is monitored by its physical location and the amount of force it is exerting on the wafer **12**. Until the contact pad **216** contacts a wafer **12**, there is no force. When the contact pad **216** contacts a wafer, the force sensing device **228** detects a force. The processor, upon receiving a force signal from the force sensing

device **228**, immediately slows down the motor **146** to achieve a final destination force by the time the gripper arms **200** secure the wafer **12** to the wafer blade **111**. This operation may not occur at the same position every time because wafer sizes may vary and the wafer may be initially seated off-center on the wafer blade **111**.

[0064] The force sensing device **228** provides real-time data to the motor assembly **144** so that the end effector can determine immediately of there is a malfunction. If, for example, the gripper arms **200** attempt to grip the wafer **12** and a wafer **12** is not present on the wafer blade **111**, or the wafer **12** slips on the wafer blade **111**, the position of motor **146** (as determined by the Hall-effect sensors) will indicate that the gripper arms **200** missed the wafer **12** and moved to far. If, on the other hand, the wafer **12** pops off the support pads **126**, the amount of force measured by the force sensing device **228** will drop immediately and indicate to the end effector that a malfunction has occurred. The thru-beam sensors **222** and **224**, in addition the force sensing device **228**, also detects the edge of a wafer **12**. In general, the force sensing device **228** and the optical sensors provide a double check system to detect a wafer **12** on the wafer blade **111**.

[0065] Figs. 12-13 illustrates yet another embodiment of an end effector. The end effector **300**, in general, includes plunger motor assembly **300** that drives a single plunger device **313** to grip a peripheral edge of a wafer. The motor housing assembly **302** preferably employs a 6mm D.C. brushless motor **346** coupled to a 57:1 planetary gearhead to drive the single plunger. As shown in Fig. 12, the motor **346** is secured to the mounting plate **354**. The motor **346** may be secured to the mounting plate **354** by several methods such as, but not limited to, a bolt or screw.

[0066] A leadscrew **350** is coupled to the output shaft (not shown) of the planetary gearhead. The leadscrew **350** drives a carriage **360** forwards and backwards along a linear path. The leadscrew **350** imparts the rotary motion of the leadscrew **350** into linear motion of the carriage **360** by an acme thread. The function of a leadscrew is known within the art and does not require further disclosure. In one embodiment, the carriage **260** may travel through a range of motion of approximately 6-7mm. It is within the scope and spirit of the invention to allow the carriage **360** to have a different range of motion. The plunger motor assembly **300** may also drive the plunger **313** by mechanical

means other than a leadscrew as long as the mechanical means may incrementally control the position of the plunger **313**.

[0067] A locating block **306** maintains the alignment of the leadscrew **350** during the operation of the plunger motor assembly **302**. An alignment rod **352** provides a low friction surface to keep the carriage **360** from rotating during its linear motion.

[0068] The single plunger device **302** comprises a gripping pad assembly **304** that includes a gripping pad **314**. The gripping pad **314** moves forwards and backwards with the carriage **360** and the leadscrew nut **306**. The gripping pad **314** may consist of a single or dual pad arrangement. As shown in Figs. 12-13, the gripping pad **314** includes an upper pad **320** and a lower pad **322**. The gripping pad assembly **304** also preferably includes dual through beam sensor arrangement **216** for sensing the edge of a wafer before the gripping pad **314** contacts the wafer. In one embodiment, the gripping pad assembly **304** houses two thru beam sensors **324** and **326** and a load cell (not shown). The gripping pad assembly **304** preferably comprises a semi-flexible material and mounts against an arm **330**. The gripping pad assembly **304** therefore flexes towards and contacts the load cell when the contact pads **320** and **322** contact the peripheral edge of the wafer. The load cell accordingly measures the force exerted on the wafer while the wafer is gripped. The gripping pad assembly **304** may also include multiple gripping pads **314**.

[0069] The end effector **300** includes several components that are similar to the previously disclosed embodiments – such as the end effector **100**. The end effector **300** includes, for example, a hard-stop **341**, a printed circuit board **332**, and a guide rail **382**. The motion of the carriage **360** is restricted by the guide rail **382** and the hard-stop **341** – similar to how the motion of the carriage **160** is restricted by the hard-stop **141** and the guide rail **182** concerning the end effector **100**. The printed circuit board **332** also includes a processor for coordinating a force feedback system similar to the force feedback system previously discussed above concerning the end effector **100**. The processor and PCB **132** may be located remotely and do not have to me mounted on the end effector **100**.

[0070] The foregoing description of preferred embodiments of the present invention has been provided for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to precise forms disclosed. Obviously, many modifications and variations will be apparent to practitioners skilled in the art. The embodiments were chosen and described in order to best explain the principles of the invention and its practical application, thereby enabling others skilled in the art to understand the invention for various embodiment and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the following claims and their equivalents.